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HANDLING AND DISPOSAL OF WASTE DRILLING FLUIDS FROM ON-LAND SUMPS IN THE NORTHWEST TERRITORIES AND YUKON

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SUMMARY

This publication is a consolidation of two reports on the disposal of waste drilling fluids from on-land wells in northern Canada. One was prepared by Hardy BBT Limited and the other by Stanley Associates Engineering Ltd. The general objectives of the two reports were to examine current practice, to consider future drilling needs and to recommend: (i) improvements in methods of disposing of waste fluids; (ii) the suitability of methods for different well types and locations; and (iii) the regulation of disposal. The Stanley report relied mainly on a literature review, whereas Hardy BBT conducted extensive interviews and a workshop involving many people active in the field.

Waste drilling fluids normally consist of suspensions of waste mud and cuttings in water or oil, to which various chemicals have been added. They may be disposed of into a sump, which may or may not be infilled ("total containment"), or directly on to land or into a water body ("non-containment"). In some cases, drilling fluids may be discharged into a sump from which the supernatant fluid is decanted and released on to land or into a water body ("partial containment"). In exceptional cases fluids may be disposed of down-hole or, in the case of oil-based muds, incinerated. Current practice in the North is to attempt total containment by disposing of fluids in a sump which is then backfilled. Decanting is rarely planned, although it has been used on an emergency basis when sumps are overfilled. Direct on-land disposal has been attempted once as an experiment. Permanent open sumps have been used in Alaska for total containment.

There are three reasons for concern about the disposal of drilling fluids. The first is their toxicity to living organisms and the second the potential for terrain damage that may accompany sump construction or disposal on to the ground surface, especially where permafrost is present. The third is the cost of disposal. The costs of practices required to counter the first two concerns must be assessed against the potential benefits.

The authors of the original reports generally endorse the practice of total containment for the disposal of drilling fluids in the North, but recommend the definition of conditions under which partial or non-containment, including emergency decanting, might be used. These conditions include classification of geographical areas by sensitivity to potential impacts and classification of drilling fluid additives by toxicity. Such classifications would enable identification of the possibility of other than total containment at the planning stage. The authors also recommend development and adoption of a toxicity test that can be applied quickly to fluids awaiting disposal during a drilling operation.

In addition to these major recommendations, this report includes many detailed recommendations intended to improve regulatory practices and to reduce or avoid practical problems encountered in disposing of drilling fluids. The regulatory recommendations are of two kinds: (i) providing more specific advice to operators on what is acceptable by means of guidelines; and (ii) improving coordination between government agencies. The operational recommendations deal mainly with specific problems of sump design, construction and abandonment.

RÉSUMÉ

La présente publication réunit deux rapports portant sur l'élimination des liquides résiduels de forage provenant des puits sur terre dans le nord du Canada. Le premier rapport a été préparé par la société Hardy BBT Limited et le second, par la société Stanley Associates Engineering Ltd. Les deux rapports avaient essentiellement les mêmes objectifs, soit d'étudier les pratiques courantes en matière d'élimination des liquides résiduels de forage, d'étudier les besoins futurs en matière de forage et de recommander:

i) de meilleures méthodes d'élimination des liquides résiduels;
ii) des méthodes conformes au type et à l'emplacement du puits; et
iii) la réglementation de l'élimination des liquides résiduels de forage.

Le rapport de la société Stanley s'inspire principalement de documents déjà publiés. Pour sa part, la société Hardy BBT a réalisé des entrevues assez exhaustives et organisé un atelier à l'intention des personnes intéressées au domaine.

Les liquides résiduels de forage consistent normalement en des résidus de boue et des déblais qui sont en suspension dans l'eau ou dans le pétrole et auxquels on a ajouté différents produits chimiques. Ils sont parfois versés dans un bassin à boue qui peut ensuite être rempli ou non ("confinement total"), ou directement sur la terre ou dans une étendue d'eau ("non-confinement"). Dans certains cas, les fluides de forage sont d'abord versés dans un bassin à boue. Les liquides remontés à la surface sont ensuite décantés et déversés sur la terre ou dans une étendue d'eau ("confinement partiel"). Dans certains cas exceptionnels, les fluides sont vidés dans un puits terminé ou, s'il s'agit de boues à base d'huile, incinérés. Dans le Nord, on tente habituellement le confinement total en versant les fluides dans un bassin à boue qui est ensuite rempli. On prévoit rarement de décanter les fluides, bien qu'on le fasse en cas d'urgence lorsque les bassins sont trop remplis. L'élimination directement sur la terre a été tentée une seule fois à titre d'expérience. Des bassins ouverts en permanence ont été utilisés en Alaska aux fins de confinement total.

L'élimination des fluides de forage pose trois risques. D'abord, les fluides de forage sont toxiques. Ensuite, la construction de bassins à boue et l'élimination des fluides directement sur la terre, surtout dans les endroits de pergélisol, peuvent

endommager le terrain. Enfin, l'élimination est très coûteuse. En outre, il faut peser les avantages que présentent ces deux risques à la lumière des coûts des contremesures nécessaires.

Les auteurs du rapport appuient la pratique de confinement total pour éliminer les fluides de forage dans le Nord. Ils recommandent cependant l'établissement de critères en vertu desquels le confinement partiel ou le non-confinement, y compris la pratique qui consiste à décanter en cas d'urgence, pourraient être utilisés. Parmi ces critères figure la classification, premièrement, des régions géographiques selon leur sensibilité, et deuxièmement, des additifs de fluides de forage selon leur toxicité, ce qui permettrait d'identifier, au stade de la planification, les possibilités autres que le confinement total. Les auteurs ont également recommandé l'élaboration et l'adoption d'un test de toxicité rapide s'appliquant aux fluides devant être éliminés au cours des travaux de forage.

Outre ces recommandations importantes, le rapport comprend de nombreuses recommandations détaillées dont l'objet est d'améliorer les pratiques de réglementation et de réduire et même éviter les difficultés pratiques associées à l'élimination des fluides de forage. On a donc recommandé de fournir des conseils plus précis à l'exploitant sur ce qui est acceptable du point de vue des lignes directrices et d'améliorer la coordination entre les organismes gouvernementaux. Les recommandations d'ordre opérationnel portent spécifiquement sur la conception, la construction et l'abandon des bassins à boue.

PART 1

INTRODUCTION

This report is a consolidation of two reports dealing with the disposal of waste drilling fluids in the North. One, Stanley Associates Engineering Ltd. (1987), was commissioned by COGLA under the Environmental Studies Research Funds Program and the other, Hardy BBT Limited (1987), by INAC under the Northern Oil and Gas Action Program.

1.1 REASONS FOR COMMISSIONING THE ORIGINAL STUDIES

Waste drilling fluids are comprised of waste muds and drill cuttings in a chemically treated suspension. These waste muds have the potential for environmental damage because they may contain toxic constituents. In addition, methods of disposing of the fluids may have secondary adverse impacts on the environment, such as the initiation of terrain instability. The containment and ultimate disposal of waste drilling fluids in an environmentally acceptable and economically feasible manner is a concern of both the petroleum industry and government regulators.

In current practice in the NWT and Yukon, waste drilling fluids from on-land exploratory operations are usually contained in below-ground sumps. On the termination of winter drilling, sumps are usually first allowed to freeze and are then backfilled and mounded. Total containment is not always practical and some contingency actions and experiments have resulted in partial containment or non-containment of waste drilling fluids in the North.

Problems of drilling fluid disposal have been reviewed by a number of authors. Hrudey (1980) found evidence to suggest that "ground upheaval and difficult winter reclamation conditions combine to provide potential contact for abandoned sump fluids with surface waters and suprapermafrost groundwater". In the Mackenzie Delta, some drilling operations are subject to annual flooding which has "resulted in direct discharge of the waste fluids in the sumps with the flood waters" (Bryant et al. 1974). This can contaminate neighbouring surface waters with toxic drilling mud components.

Sumps may contribute to significant terrain disturbance. In a survey of over 60 abandoned well sites in the Mackenzie Delta, the Arctic Islands and the interior Yukon Territory, French (1980) indicated that approximately 25 per cent of the sites experience terrain disturbance problems related either directly or indirectly to sumps and the containment of waste drilling fluids. He suggested that increases in sump failure and terrain disturbance in the late 1970's were related to the greater depths to which Arctic wells were being drilled;

larger volumes of drilling fluids and longer times were required for site preparation, drilling and termination. Drilling operations were more likely to extend into the summer months when the movement of heavy equipment and supplies around sensitive sites could lead to considerable terrain disturbance. In the 1980's many wells have been drilled partly, or totally, during the summer due to rig availability, logistical considerations or operating company preferences.

As the necessity for larger sumps and the potential for terrain disturbance increases, alternate approaches to waste disposal have been examined. Several authors have re-evaluated the need for containment of drilling fluids in below-ground sumps. French and Rossiter (1985) and Myers and Barker (1984) evaluated surface disposal as an alternative.

The Territorial Land Use Regulations appear to have worked satisfactorily for the majority of wells drilled in Arctic Canada (French 1980). However, total containment of waste fluids in below-ground sumps is hindered in the Arctic by volume requirements, transportation constraints between breakup and freeze-up, and the conditions resulting from sub-zero temperatures. As well, the greater depths to which oil wells will be drilled when economic conditions improve, the increased requirements for anticipated production well drilling, and the increasing probability of operations extending into critical summer months are important factors which limit the effectiveness of existing regulations. Recognition of these problems led to the commissioning of the original studies.

1.2 OBJECTIVES AND METHODS

The Stanley Associates Engineering Ltd. (1987) study was a literature review. Its objectives were:

1) To review and summarize all ALUR reports and other relevant information from published and unpublished reports.

2) To synthesize the above findings so they can be evaluated for possible integration into environmental guidelines or regulations.

3) To review existing treatment technologies for waste drilling fluids and to identify practical methods.

4) To examine existing guidelines concerning disposal of waste drilling fluids to make appropriate recommendations that recognize the unique northern terrains and their constraints for disposal.

5) To identify major deficiencies and suggest research programs to fill the gaps.

The objectives of the Hardy BBT Limited (1987) study were as follows:

1) To evaluate the current practice and focus on problem areas in handling of waste drilling fluids in exploratory drilling for oil and gas in the NWT and Yukon.

2) To develop a concept of containment, and treatment (for example: flocculation, filtration, incineration) and disposal which would minimize potential impacts based on analysis of natural conditions, current industry practices, available technology, and the latest scientific knowledge related to the subject and to environmental protection.

3) To suggest principles reflecting the results from achieving both of the above stated objectives. The principles should be clear, meaningful, practical and enforceable within DIAND's mandate. The principles should be acceptable to the industry and government agencies with responsibilities in the NWT and/or Yukon.

4) To suggest criteria for: (a) sump site selection, (b) sump decanting, and (c) allowing non-containment (based on drilling mud recipe, terrain, hydrology, etc.).

5) To suggest measures for dealing with abandoned sumps to reduce or eliminate any major potential environmental effects.

6) To suggest any follow-up actions which may be advisable to support the above stated objectives. The study's general objective is to enhance future practices in the handling of waste drilling fluids and to reduce or eliminate potential environmental impacts as well as various costs on the side of both government and industry.

Hardy BBT conducted a literature search and used interviews and a workshop to gather information. Interviews were conducted with 18 representatives from oil companies operating in the North, 19 government regulators and eight scientific researchers. The workshop was held in Calgary on March 2 and 3, 1987. Attendees included representatives from industry and government, several of whom reviewed the draft Hardy BBT report and contributed suggestions to the final version.

The objective of consolidating the Hardy BBT and Stanley reports was to bring together the information gathered and recommendations put forward by the authors. The resultant synthesis is intended to guide future initiatives in the improvement of drilling fluid disposal practices.

1.3 ORGANIZATION OF REPORT

The report has seven parts of which Part 1 is this introduction. Part 2 explains what drilling fluids are and outlines the types of drilling mud system used in the North. It describes the nature, volume and chemical composition of drilling waste effluents. Part 3 describes current regulatory and operating practice in the disposal of drilling fluids in the North. Part 4 defines the economic, environmental and regulatory concerns posed by drilling fluid disposal in the North. It then relates these concerns in detail to each stage of a drilling operation. Part 5 reviews the various approaches to disposal i.e. total, partial and non-containment. It discusses their applicability to different types of drilling operation, drilling fluid and well site, and suggests possible improvements. Part 6 lists recommendations for further work. Part 7 provides a list of references cited.

1.4 AUTHORSHIP

All parts of this publication incorporate material from both Hardy BBT Limited (1987) and Stanley Associates Engineering Ltd. (1987). Most of the references to the literature are from Stanley and most of the regulatory material is from Hardy BBT. Part 3 is drawn largely from Hardy BBT with additions from Stanley, especially in 3.2.2 and 3.3. Parts 4.1.1 and 4.1.2 are mostly from Stanley, but 4.1.3 and 4.2 are mostly from Hardy BBT. Part 5.1 is from Stanley, but the rest of Part 5 is based on Hardy BBT with substantial additions from Stanley. Part 6 is from Hardy BBT.

PART 2

THE NATURE AND FUNCTIONS OF DRILLING FLUIDS

This part of the report briefly describes the kinds of drilling mud systems used in northern Canada. It then describes the nature, volume and chemical composition of the effluents produced by these systems.

2.1 MUD SYSTEMS

The primary functions of drilling fluids are: removal of rock cuttings from the bottom of the drill hole, control of formation pressures, protection of productive formations, cooling and lubrication, hole stabilization and protection against corrosion. Drilling muds are comprised of various components and additives that contribute to the ability of drilling muds to fulfil these functions.

In the northern regions of Canada one of three types of drilling mud system is usually employed: brine-based, fresh water-based or oil-based. Brine-based muds are commonly used for drilling below 2000 m. They are generally composed of potassium chloride (potash), bentonite (montmorillonite clay), sodium hydroxide (caustic soda), and an XC polymer (xanthan polymer). The latter is a bacterial product of sugar beets and is used to provide both viscosity and density. Bentonite is also used as a viscosifier. Caustic soda is used primarily to control pH and secondarily to remove calcium. The potassium chloride lowers the freezing point and allows the use of cold mud to reduce thermal damage to permafrost.

Fresh water-based muds are commonly used in holes less than 2000 m deep and in the top 2000 m of deeper holes. The muds are generally composed of bentonite, XC polymer and caustic soda. Below 500 m, barite is used as a weighting agent to increase mud density when abnormal formation pressures are encountered. Lignosulphonates (ferrochrome organic compounds) may be added to the mud system to reduce viscosity when heavier mud is used. Other additives (and their purposes) are: carboxymethyl cellulose (CMC) (water loss); salt and lime (flocculants; lime to thicken surface mud); SAPP (thinners); sawdust and quickseal (loss of circulation); and Drispac and other fibrous materials (fluid loss reducers).

Oil-based mud systems are infrequently used in northern Canada at present. They are particularly suited for use in extremely water-sensitive shale formations, deep salt formations and abnormally pressured formations. In the future, oil-based muds may see increased use in the North to reduce problems such as torque build-up, hole drag, sloughing shales and formation damage. Deposition of oil-based muds into sumps is generally prohibited so they are not released as effluents.

There is a fourth type of drilling system that uses a foam rather than a mud. Air drilling is effective where there are no hydrocarbons in the formation and no water flows. It is used most commonly in the upper portion of holes where the formation is fractured and cannot support a fluid system. The waste product of this system is a foam containing very fine particles. It is discharged either into a sump, where the foam breaks down leaving the very fine particles, directly onto the surface where the result is the presence of the fine dust, or more commonly into the flare pit where it is burned.

There are many drilling mud additives, in addition to those mentioned above, that may be used in lesser quantities. Miller and Honarvar (1975) describe some of those most frequently used and their contributions to drilling mud function. Additives used will depend on the properties of the mud required as the depth of the drilled hole increases and the subsurface formations change.

2.2 WASTE EFFLUENT

2.2.1 Nature of Effluent

Waste effluent is a complex and highly variable mixture that may contain drilling muds, altered drilling muds, completion fluids, organic bactericides, organic and inorganic compounds, various detergents used in rig wash, and waste cement.

The chemical composition of drilling muds may be altered considerably by the addition of rock cuttings. Strosher (1980) speculated that a variety of compounds may be produced as a result of high temperature and pressure and chemical interactions that may occur within the well bore. Microbiological degradation of organic additives has led to the use of biocides which also become part of the waste effluent.

Drilling waste effluent usually includes water containing oil, grease and dirt from washing of the rig. The volume of wash water deposited in the sump varies considerably among operators: some identify it as the major component of fluid in the sump and others do not use it at all. One operator skims hydrocarbons off the wash water by filtration before it is discharged into the sump; another attempts to reuse the wash water after removing the grease and dirt through filtration. Most operators reduce the volume of wash water by using high pressure wash guns.

Some operators deposit waste cement from the hole into the sump. The volumes involved are generally negligible in relation to the size of the sump. Esso deposits 1-5 cubic metres of excess cement per well. Gulf uses 80 to 100 per

cent extra surface cement and 20 to 30 per cent extra down-hole cement on its wells. This surplus is deposited in the sump. The cement sets before it freezes in the sump, helping prevent leaching of fluids.

2.2.2 Volume and Chemical Composition

The volumes of drilling mud effluent generated from drilling operations can be large. Bryant and Hrudey (1975) found that a typical 3000 metre deep well produced approximately 4000 cubic metres of waste fluid. In the late 1970's, Arctic wells were drilled to greater depths, generating larger volumes of effluent and necessitating the construction of larger sumps (French 1980).

The typical range in the chemical composition of the effluent is illustrated by several published sump fluid analyses. Chemical analyses of fluids from 12 drilling operations (onshore and offshore) in northern Canada found the total dissolved zinc content to be as high as 8.5 mg/L (Siferd 1975). In addition, the maximum observed quantities of dissolved copper were 7.9 mg/L, total dissolved iron was 5.3 mg/L and dissolved chromium was 27 mg/L. Bryant et al. (1974) listed the typical characteristics of ten sump fluids resulting from drilling operations in the Canadian North as having "high concentrations of organic carbon, total nitrogen, phosphorous, suspended solids, chemical oxygen demand, and chromium". In Alberta, Strosher (1980) investigated the organic constituents of ten sump fluids and found that organic carbon levels varied from 30 mg/L to 10 000 mg/L. The organic compounds of particular importance for potential environmental contamination were aromatic hydrocarbons which ranged from 0.2 to 2920 mg/L and aliphatic hydrocarbons which ranged from 0.1 to 1410 mg/L. Additional waste drilling fluid analyses may be found in Hrudey (1979), Falk and Lawrence (1973) and French (1985).

Sources of some of the potentially troublesome constituents are identified as follows:

i) Suspended solids in drilling fluids include insoluble salts such as barite and gypsum, clays such as bentonite, and lost circulation control products such as sawdust and redwood fibre (Land 1974);

ii) High specific conductivity of sump fluids is largely due to the use of potash, caustic soda, bicarbonate of soda and acid pyrophosphate (Hrudey 1979). In addition, the infiltration of high salinity waters such as those found in the Mackenzie Delta may contribute to the high specific conductivity of sump fluids (Hrudey 1979);

iii) High pH levels in sump fluids are often caused by the use of caustic soda in the mud formulation;

iv) Potash is the main source of potassium and chloride, and caustic soda is the principal source of sodium;

v) Chromium is contributed largely by any of three types of chromium lignosulphonate compounds (Land 1974): ferrochrome lignosulphonate (Q-Broxin, Peltex), chrome lignosulphonate (Spersene) and chrome modified sodium lignosulphonate (Unical). Corrosion inhibitors and bactericidal additives contribute chromium to a lesser degree;

vi) Other trace metals such as mercury, zinc, iron and lead may be contributed by impurities in barite. Lignosulphonate, to a lesser degree, may be a source of zinc and iron;

vii) Phosphorous probably results from the use of sodium acid pyrophosphate (Bryant et al. 1974);

viii) Barite is the major source of barium;

ix) Organic carbon is contributed mainly by organic polymers and lignosulphonate (Hrudey 1979); and

x) Oil and grease result from either drill cuttings, lubrication or rigwash detergents. Bryant et al. (1974), however, speculated that the apparent high concentrations of oil and grease in drilling muds are probably due to analytical error because of "interference with the ether extractables test by the organic polymer material used in the mud". On the other hand, Strosher and Bogner (reported in Appendix D of Bryant and Hrudey (1975)), showed high loads of hydrocarbons in waste drilling fluids. They also found poor recoveries of spiked hydrocarbons, suggesting that standard methods may underestimate actual concentrations. Soniassy (1983) found no satisfactory method for the analysis of oil and grease in drilling muds. However, he did suggest the use of azeotropic distillation with methylene chloride as a solvent until a more reliable method of analysis is found.

PART 3

CURRENT HANDLING PROCEDURES FOR WASTE DRILLING FLUIDS IN NORTHERN CANADA

This part of the report describes current practice in the disposal of waste drilling fluids in northern Canada. It deals in turn with regulation; planning, design and operation of typical procedures; and unusual procedures.

3.1 REGULATORY REQUIREMENTS

Onshore exploration wells in northern Canada on lands subject to the Territorial Lands Act and the Oil and Gas Production and Conservation Act require the issuance of a Land Use Permit from DIAND and an Authority to Drill a Well from Canada Oil and Gas Lands Administration (COGLA). Depending on the need for borrow materials at the drill site, a Quarrying Permit may also be required. Wells drilled on Commissioners Land are subject to the Commissioner's Land Act.

The Terms and Conditions attached to the Land Use Permit are the principal regulatory requirements affecting surface activities at onshore wells. These normally require that in-ground sumps be constructed to completely contain anticipated volumes of drilling fluids. Sump decanting, if necessary, must be carried out in accordance with the Land Use Permit. If the sump fluids are to be discharged directly into a water body, it must be demonstrated that they do not contain any wastes.

Well sites are inspected by DIAND Land Use Inspectors and COGLA Engineers. The former are concerned with surface activities; the latter with subsurface activities, the effect of surface activities on subsurface activities, and drill rig safety.

3.2 TYPICAL PROCEDURES FOR WASTE FLUID DISPOSAL

3.2.1 Sump Placement and Construction

Well locations are determined by subsurface geology and can only be varied to a minor extent. Sump location is tied to the well site. To the extent possible: level surfaces and high ground, away from drainage ways and at least 30 m from a stream (100 m if possible) are selected; in permafrost terrain, ice-rich soil is avoided; in non-permafrost terrain, porous materials such as sand and gravel are avoided; and sites with groundwater are also avoided.

Some operators place sumps upslope of the rig so that they will be in cuts rather than fills. Upslope locations are also desirable when the excavated material is used to construct the rig pad because it is easier to move material

downslope than upslope. Other operators place sumps downslope of the rig in order to discharge fluids by gravity from the rig to the sump. An effort is generally made to place sumps wherever the ground is most level.

When terrain conditions at a well site are unsuitable for sump construction, (e.g. preponderance of ice-rich soil or physical constraints such as in foothill terrain), remote sumps are considered. To be economically feasible these usually have to be within a few kilometres of the site and accessible by road.

Investigation of subsurface conditions prior to sump construction also varies among operators. Activities vary from carrying out a drilling program to ascertain ground conditions, particularly ice contents at the well site, to examining the soil conditions at the shot holes for the explosives used before sump excavation. Frequently sites are selected on the basis of a field investigation and on past experience in the area.

The size of a sump depends on the depth of the hole planned to be drilled and, with some operators, the expected duration of drilling. Experience from previous wells in the area also plays a part in determining sump size. Some operators increase sump size if the sump is to be open during summer when runoff may add to fluid volume. A 1.2 m freeboard is a standard requirement in Land Use Permits and is taken into account when sizing sumps. Sizing formulae, based on the length of hole, are used by most operators. Esso uses 1.3 cubic metres per metre drilled. PetroCanada constructs 6500 cubic metre sumps in which it puts 4000-5000 cubic metres of waste fluid. The formula used by the Petroleum Industry Training Service (PITS) is generally found to be acceptable: sump volumes in a range from 0.78 to 1.3 cubic metres (1 cubic metre = 6.3 bbls) per metre of hole drilled (PITS 1983). The factor of 1.3 cubic metres/metre drilled, should be used for hole depths greater than 1500 metres.

In the continuous permafrost zone, sumps are constructed by drilling and blasting, followed by ripping and excavation using cats. In the discontinuous permafrost zone excavation by cats alone is the norm, with blasting used if bedrock is present. The material excavated from the sump is stockpiled for covering the sump later.

In some cases if a sump constructed in permafrost is to be left open through the summer, the sump walls are sloped to reduce sloughing into the sump upon thawing. Some operators insulate the south-facing wall with matting or a "sandwich" consisting of insulating foam in a wire and wood frame. Matting is also used to protect the stockpiled overburden from thermal erosion over summer. In permafrost-free areas, a backhoe may be used to excavate the sump with vertical walls. Drainage around sumps is diverted by snow dikes during early spring and earthen or sand bag dikes in summer.

Estimates of the cost of constructing sumps vary from $100,000 to $500,000 in the Mackenzie Delta and the High Arctic, to $60,000 in the Norman Wells area, to $14,000 in the southern Territories. Estimates vary widely because operators include different elements in calculating sump costs. For example, the transportation of earth moving equipment may be included with sump construction costs in some cases and with general rig site preparation in others.

3.2.2 Operational Procedures and Contingency Measures

During drilling, waste fluids are normally discharged directly into a sump. Direct disposal on to tundra has been attempted on an experimental basis in Alaska and the Canadian Arctic (See section 3.3).

Some operators attempt to reduce the volume of fluids discharged and the size of sump required by using high pressure wash guns when washing the rig and reusing the drilling fluids. The reuse of drilling fluids has been practiced in northern Canada. However, most drilling operations are carried out in winter and the waste drilling fluids may freeze soon after entering the sump. This makes the simple recirculating procedures used in southern Canada unworkable. Any scheme for reuse has to be either protected from the cold or restricted to summer operations. An enclosed system has been used by NorthCor Energy Ltd. at a recently drilled well in the Liard Range north of Fort Liard, where terrain restrictions allowed for only a small sump. The procedure involved mechanical separation of solids and fluids, followed by the addition of a polymer and recentrifuging to remove the fines that could not be removed by mechanical means alone. Water plus drilling chemicals were reused. Only the solids went to the sump. This system, used during both winter and summer drilling allowed for the reuse of about 75 per cent of the water. The system, which cost about $3,000 per day, was cheaper than using a remote sump. The usual approach to recirculating involves construction of a berm across the sump and the use of flocculants to remove the solids. This system, too, can be expensive. Gulf spent $250,000 to recirculate the fluids for a 1600 to 1800 m hole.

Treatment of drilling fluids to reduce toxicity is common. Drilling fluids that are simple in composition are easier to treat. Experience in the Canadian Arctic has shown that simple drilling fluid compositions can be adequately treated in sumps by flocculation, dilution and pH adjustments to lower the toxicity level. Esso Resources Canada Ltd. dilutes drilling mud 25:1 with sea water and adjusts the pH to less than 8.5 prior to disposal (Friesen 1980). Friesen noted that no serious environmental hazards have been observed. However, Esso is still monitoring disposal methods continually to evaluate long term effects.

More complex drilling muds are harder to treat. Studies on the environmental effects of drilling fluid additives indicate that the majority produce minimally toxic or phytotoxic effects (Falk and Lawrence 1973; Zitko 1975; Miller and Honarvar 1975). Strosher (1980) conducted a study to identify the types of organic compounds present in the sump and to determine their effects. He found that the majority of the organic constituents present were unaltered mud additives. Therefore selection of the less toxic alternatives from the many additives available would be one way to achieve a lower level of toxicity. The controlled use of hydrocarbons (from oil-based drilling muds and/or cleanup operations) and removal of the hydrocarbons for separate disposal would also reduce toxicity.

Other operational procedures related to sumps include diverting surface runoff away from sumps open during the summer, insulating walls of sumps open during the summer, and spraying the sump fluid into the air above the sump to increase evaporation. Fluid levels in sumps are monitored to ensure the 1.2 m freeboard is maintained and that excessive sloughing of the walls does not occur.

Operators' contingency planning focusses on the eventuality of the sump filling prior to well completion. The following alternatives are considered: construction of a second sump; decanting; and downhole disposal after the well is completed.

Construction of a second sump is common because of the length of time usually required by regulators before an approval to decant is granted. Construction may be carried out adjacent to the existing sump or at a remote site. The integrity of the existing sump may be affected if blasting is required.

Decanting on land requires a Land Use Permit. If the decanted fluid is to enter a water body, the Water Board may require a Water License if the fluid contains waste (as defined in the Northern Inland Waters Act). The sump fluid normally has to be analysed for toxicity and treated, if necessary, prior to decanting. Decanting has also been carried out by spraying on land where terrain conditions indicate little probable impact on water bodies or nearby vegetation.

Downhole disposal is uncommon. It has been used in the High Arctic and involved the pumping of the clean water and low solids portion of the fluids into the hole.

3.2.3 Sump Abandonment

Land Use Permit Operating Conditions normally require that waste drilling fluids be totally contained upon well completion. The approach to sump abandonment, therefore, is to fill the sump in, trapping the waste drilling fluids.

Sumps in all areas of the North are easiest to abandon during winter when the sump fluids are likely to be frozen. Since most drilling (approximately 95 per cent) occurs over winter, this scenario is the norm. The frozen sump is backfilled with the excavated material from the pit to form a cap. The thickness of the cap approximates the depth of fluids in the sump and serves to counteract any thawing in the backfill and sump contents. Small depressions may develop in the cap but the surface is intended to stay above the original ground surface. Since sumps are excavated below the active layer, the fluids themselves are not expected to thaw. In some cases, a high salt concentration may depress the freezing point of the fluid and cause an unfrozen layer to persist within the frozen sump fluids. The cap is seeded, or left to revegetate naturally. When abandoning wells in the Mackenzie Delta, seeding (where required) must be done after spring flooding.

If sumps in permafrost are abandoned in summer, the fluids will not be frozen. Potential abandonment procedures in this case include:

i) Decanting the uppermost fluids prior to infilling;

ii) Mixing the fluids with the fill outside the sump prior to backfilling the sump; and

iii) Filling in the sump and mixing the fluids and soil in the sump.

Sumps in permafrost-free terrain are usually abandoned by squeezing. As soil is added, the fluids are squeezed out. These fluids are then mixed with more soil and returned to the sump. As more solids are added, the surface firms up. Fluid disposal by a trenching method has been tried in the southern Northwest Territories but the presence of water saturated soils and frozen soils should rule out such disposal. Trenching of sump fluids can be done effectively during summer months in ice-free dry soils which can absorb the fluid.

3.3 UNUSUAL PROCEDURES

In response to the various environmental problems associated with conventional sump disposal procedures, alternative methods of waste disposal have been investigated in the Canadian North. The most important of these is direct disposal on the tundra.

Myers and Barker (1984) evaluated direct tundra disposal of reserve pit fluids at Prudhoe Bay, Alaska. Drilling muds from three abandoned reserve pits were pumped directly onto the tundra at a rate of approximately 9.5 litres per second. The authors found that mechanical and physical damage occurred only in the immediate vicinity of the discharge hose and that this damage could be greatly reduced with devices that would disperse the discharge over a wider area. They concluded that the "direct tundra disposal of drilling reserve pit fluids can be an environmentally acceptable alternative under certain circumstances". The concentration of salt in the pits had the largest impact on the tundra. Below 2000 mg/L total dissolved solids (TDS), there were no significant effects on the most sensitive tundra vegetation, and above 4000 mg/L, extensive physiological stress was induced. This experiment could be regarded as an extreme case of decanting rather than direct on-land disposal.

French (1985) investigated environmental impacts resulting from the disposal of waste drilling fluids directly on tundra at Ellef Ringnes Island, NWT. The well site selected for the study was located in an arid polar desert environment, supporting little vegetation or wildlife. The muds used were relatively non-toxic and of low volume. Below-ground containment was difficult without causing substantial terrain disturbance. The drilling fluid waste was placed into a natural depression some 75 m downslope of the drilling rig. Summer thawing resulted in the movement of a thin (1 to 5 cm) film of mud, downslope of the main disposal zone. Analyses of the nearby creek indicated that soluble constituents of the waste drilling fluids (sodium, potassium and chloride) were being leached out while little or no leaching of heavy metals was occurring.

French concluded that terrain disturbances resulting from direct disposal of drilling wastes onto tundra were considerably less than those that might have occurred if a sump had been constructed. He stated that "direct surface disposal may be an operationally acceptable procedure in those polar semi-desert environments where plant and animal productivity is low, suitable site-specific conditions are present for partial surface containment, and the potential for terrain disturbances is high".

PART 4

CONCERNS ABOUT HANDLING OF WASTE DRILLING FLUIDS

Part 4 discusses problems that arise in disposing of waste drilling fluids from exploratory drilling in northern Canada. It begins by setting out environmental concerns from a general perspective, proceeds to a consideration of regulatory problems and then examines the various concerns in a step by step review of the drilling process. As part of that review some consideration is given to the costs and benefits of various waste handling procedures.

4.1 TYPES OF CONCERN

4.1.1 Economic Concerns

Concerns about the handling of waste drilling fluids in the Northwest Territories and Yukon may be classified as economic, environmental and regulatory. Economic concerns are the cost of measures required to contain or dispose of wastes, the costs of the failure to do so and the relationship between the two. Specific examples are cited in section 4.2.

4.1.2 Environmental Concerns

There are two types of environmental concern:

i) Physical disturbance of land, both on and adjacent to drilling sites, may result from sump construction, sump failure or reclamation procedures; and

ii) Chemical contamination of local surface and groundwater may cause damage to terrestrial and aquatic vegetation, as well as to aquatic organisms. Changes in water quality may affect residential and other local water uses.

4.1.2.1 Physical Disturbance

Chemical effects resulting from disposal of drilling fluids into sumps have been found to be minor compared to physical damage to terrain (Smith and James 1979; 1980a; 1980b; 1980c). Physical disturbance can also increase chemical contamination by reducing the effectiveness of containment practices. In a survey of over 60 abandoned well sites in the Mackenzie Delta, the Arctic Islands and the interior Yukon Territory, French (1980) found that approximately 25 per cent of all well sites experienced terrain disturbance that was related directly or indirectly to sump containment of waste drilling fluids. The problems were of three types: (i) non-containment during drilling; (ii) melt-out during summer operations; and (iii) restoration activities.

Non-containment during drilling usually results from a sump being too small for a given operation. This necessitates the construction of additional sumps or modifications to existing sumps, both of which can result in considerable terrain disturbance (French 1980).

Spillage of sump fluids or enlargement of sumps may occur during melt-out (i.e. either during a summer drilling operation or when a sump is left open during the summer). This is a condition which results from the thermal effect of sump fluids upon the adjacent permafrost, combined with the effect of positive ambient air temperature upon exposed permafrost in the sump walls (French and Smith 1980).

Problems which occur during restoration are frequently associated with operations in which the sump has remained open during the summer. The most important of these are:

i) The "volcano" effect, when sump fluids are not completely frozen and the frozen surface breaks under the weight of the overburden from sump infilling;

ii) Sump subsidence and collapse during the summer following restoration when snow or ice was incorporated into the infill or water seeped or drained into the sump in summer;

iii) Loss of infill volume, the result of melt-out of ice during summer in the sump infill material, may generate a standing water body over the sump which serves as a heat sink. This problem may be acute in areas where there is a lack of accessible aggregate and where the infill is ice-rich;

iv) Leakage of fluids if ice lenses in sump walls melt out or if the sump is too full when infilled;

v) Excessive terrain disturbance by heavy equipment usually: (a) during summer operations on well vegetated, ice-rich tundra terrain; (b) where additional sumps are constructed; and (c) where technical drilling problems are encountered.

4.1.2.2 Chemical Contamination

Aquatic Biota

A number of studies have evaluated the effects of discharges of drilling fluids on aquatic environments, particularly fish. The toxicological properties of industrial wastewater are routinely assessed by the acute lethality bioassay technique. Test results are commonly expressed as the 96 hour LC 50, which is defined as that concentration in percent by volume or mass per unit volume which kills 50 per cent of the test species population in 96 hours. The lower an LC 50, the greater the toxicity.

In the Canadian North, fingerling rainbow trout are employed as the test species, but the appropriateness of the test has been questioned. Soniassy (1983) suggested that the threespine stickleback, found in marine and fresh waters in the Arctic and sub-Arctic, might be a more appropriate test species in assessing the toxicity of drilling fluids in northern Canada. Another researcher (Shaw 1975) noted that acute toxicity studies do not identify sublethal effects on the test species. For example, if the test species does not die within a specified test time (i.e. 96 hours), the fluid is not necessarily non-toxic; the test species may actually die some time later or it may become sterile.

The results of acute toxicity studies using either drilling fluids or sump fluids (made up of waste muds, drill cuttings, waste lubricating oils, and rig washwater) are highly variable. For example, Falk and Lawrence (1973) found that drilling fluids were acutely toxic to lake chub and rainbow trout (96 hour LC 50 ranged from 0.83 to 12 per cent), but a single sump fluid (supernatant) was less toxic (LC 50 of 81 per cent). Weir et al. (1974) found a wide range (8.6 to 100 per cent) for sump fluids generated at various times during drilling operations in the Mackenzie Delta. Moore et al. (1975) investigated the acute toxicity of drilling fluids to rainbow trout from nine Arctic rigs. It varied from 0.29 to 85 per cent with one sample showing no apparent toxicity at all. The causes of acute toxicity varied. No blanket statement could be made as to the source(s) of toxicity of the mud samples. The toxicity of each sample was related to the individual areas drilled, company and rig practices and the conditions encountered. In similar studies of the acute toxicity of drilling fluids to rainbow trout, Bryant and Hrudey (1975) concluded that "screening of the chemical characteristics in relation to acute lethal toxicity results failed to identify any one particular parameter responsible for acute lethal toxicity in all samples, but several parameters were implicated for various samples". Sprague and Logan (1979) found that the lethal toxicity to rainbow trout of whole drilling muds from the Mackenzie Delta varied from 0.83 to 5.3 per cent.

Several toxicity studies have been conducted on aquatic organisms other than rainbow trout. Campbell (1975) found that there were no measurable effects on the feeding habits or behaviour of fish populations in receiving waters as a result of the discharge of fluids into a small (100 ha) tundra lake in northern Canada. B.C. Research (1975) investigated the acute toxicity of seven drilling fluids from Arctic drilling operations to both freshwater and saltwater organisms including rainbow trout, coho salmon, and various intertidal invertebrates (e.g. mussel worm, clams and shrimp). They concluded that the acute toxicity of waste water to saltwater organisms was just as great as that to freshwater organisms. Hardin (1976) found that only one

of four fluids collected from the Mackenzie Delta was not acutely toxic to any of the tested species (fish, chironomids and amphipods). The other three were toxic to one or more of the test species. Tornberg et al. (1980) investigated the acute toxicity of 30 drilling fluids obtained from the Beaufort Sea and found that the 96 hour LC 50 for isopods, snails and polychaetes ranged from 40 to 70 per cent, mysids ranged from 6 to 22 per cent, amphipods from 22 to 38 per cent, broad whitefish from 6 to 37 per cent, fourhorn sculpin from 4 to 35 per cent, arctic cod from 20 to 25 per cent and saffron cod from 17 to 30 per cent.

Didiuk and Wright (1975) studied the effects of thin layers of drilling waste from the Mackenzie Delta on the survival of chironomid larvae, using the emergence of adults as an index of survival. They found that for an exposure period of 29 days there was 62 per cent survival with a 1 mm layer of waste mud, 47 per cent survival with a 3 mm layer and 12 per cent with a 7 mm layer.

Land (1974) reviewed the available literature and concluded that potassium chloride was more toxic to fish and crustacean zooplankton than either calcium or sodium chloride, and that compounds possessing chromium were toxic to aquatic animals in concentrations of less than 1 mg/L. He also found that the acute toxicity of hexavalent chromium (harmful at 0.1 to 0.4 mg/L) was greater than trivalent chromium (harmful at 0.3 to 1.0 mg/L). Drilling fluids were reported to contain up to 140 mg/L of trivalent chromium and up to 450 mg/L of hexavalent chromium. Bactericides, lubricants and detergents used in drilling operations were toxic to fish at concentrations of less than 100 mg/L. Hollingsworth and Lockhart (1975) investigated the toxicity of various thinning agents used in simple sodium montmorillonite drilling fluids to deflocculate and maintain proper gel strengths. Results of this study indicated that the tannin class of thinners, exemplified by quebracho, has a considerably lower LC 50 than any of the other products tested and can be classified as highly toxic. All other products tested were classified as low-toxicity agents.

Shaw (1975) reviewed the results of some 600 studies with non-standard fish bioassays done on various drilling components at the Energy Resources Conservation Board Laboratory of the Province of Alberta. He corroborated the findings reported by others as well as noting:

i) Diesel fuel from fuel spills and machine cleanup, depending upon the method of manufacture, may be very toxic;

ii) Corrosion inhibitors from drilling muds or packer tests are generally very toxic;

iii) Small amounts (less than 1 mg/L) of soil sterilants and weed poisons used on the lease are often very toxic to animals;

iv) Aluminium salts, trivalent metal salts and alums, which may be used to clarify sumps, may produce a very toxic solution if the pH is not carefully controlled. The metal salt that precipitates in the pH 5 to 7 range can be very soluble outside this range;

v) Emulsion breakers used in muds seem to be very toxic, in the same class as some corrosion inhibitors. Some may have similar structures; and

vi) Low concentrations of sodium lauryl sulphonate used as washing compounds produce very toxic solutions.

Beckett et al. (1975) investigated the acute toxicity of 34 drilling components. Testing for each component indicated that the acute toxicities ranged from concentrations less than 1 mg/L to concentrations greater than 50 000 mg/L. The authors identified the need to examine the possible synergisitic and antagonistic effects of combinations of the components.

Twenty one drilling components were examined for acute toxicity by Sprague and Logan (1979). They found that seven of these components (paraformaldehyde, capryl alcohol, and five surfactants) were lethal at concentrations below 100 mg/L while the remainder were toxic only at higher concentrations. They found no evidence for synergistic toxicity and limited evidence for direct addition of toxicities for mixtures of these components. There was clear anatagonism in some of the mixtures tested, most notably with bentonite reducing the toxicity of other components. Six of the seven most toxic components lost toxicity upon aging for 16 days in water while the surfactant, B-Free, increased sharply in toxicity.

Lawrence and Scherer (1974) studied the sublethal effects on rainbow trout and whitefish of mud fluids and supernatants from drilling operations in the Beaufort Sea. Fish responses were neutral at 55 mg/L, exhibited a preference at 1000 mg/L and avoidance at 10 000 mg/L. The highest concentration was 0.2 of the highest non-lethal concentration in a 28 day static bioassay. The authors felt that the attraction at concentrations less than 1000 mg/L may be detrimental over a long period of time because "lengthy, or repeated exposure to relatively low concentrations can prove lethal". The standard acute toxicity test cannot detect this type of effect.

Vegetation and Soils

Few studies have been published on the effects of drilling fluids or their additives on plant growth. Most of them are more applicable to southern Canada than to Arctic environments. For example, Miller and Honarvar (1975) and Miller et al. (1980) investigated the effects on corn and beans of 31 common drilling additives, mixed into fertile soil. They found that the most severe reduction in plant growth resulted from addition of sodium dichromate, diesel oil, potassium chloride, or a mixture of calcium lignosulphonate and lignite. Effects of whole drilling fluids on beans and corn were investigated by Miller and Pesaran (1980). Excess soluble salt and exchangeable sodium were identified as the causes of reduced plant growth. A study of plant uptake of trace elements (Nelson et al. 1984) from drilling muds found that zinc, copper, cadmium, lead and arsenic were available for uptake by plants, but that barium was not readily available.

Strosher et al. (1978) investigated the effects of controlled spillage of seven sump fluids on field plots in the Alberta Foothills. Fluids from potassium chloride water-polymer drilling muds were the most harmful to soils and vegetation. The fluids from fresh water-gel drilling muds were the least harmful. The plant damage appeared to result from direct tissue contact at the time of the spill and uptake of the components following the spill.

Smith and James (1979; 1980a; 1980b; 1980c), conducted several studies in the Yukon, Mackenzie Delta and the High Arctic. They concluded that chemical damage was secondary to physical damage to the plants. Physical damage resulted from operations related to both the sump restoration and drilling. At specific sites, however, they were able to find chemical damage to plants attributable to high chloride concentrations in the soil, high levels of potassium and high levels of sodium.

Smith and James (1980a) felt that chemical damage to plants in the High Arctic would be small. First, the soils are rich in calcium. This reduces the damage due to sodium. Secondly, the temperatures are generally low. This reduces plant toxicity effects. Lastly, most plants are already resistant to salinity.

Myers and Barker (1984) investigated the effects on vegetation and soils of direct disposal of drilling fluids on the tundra at Prudhoe Bay, Alaska. They found that at high concentrations of dissolved solids (greater than 4000 mg/L), vegetation showed extensive physiological stress. Willows were the least tolerant of salt, while perennial herbs showed either temporary or no physiological stress. Graminoid species showed no apparent reaction to the discharge of pit fluids. Tundra disposal did not significantly affect soil pH or conductivity levels.

Water Quality

Very few studies have been conducted to assess the chemical contamination of inland freshwater bodies by drilling fluids. The severity of contamination would be highly variable, depending on the size of the freshwater body, the chemical characterisitics of the receiving waters and the volume and composition of the discharge.

Hrudey et al. (1974) examined surface waters near six abandoned sumps on the Mackenzie Delta. The authors found that small neutral surface-water pools and ponds within a few hundred feet of the abandoned sumps were usually contaminated. This contamination was evidenced by high concentrations of chloride, sulphate, organic carbon and sodium. No measurable levels of barium, chromium or aluminium were found in any sample. At only one site was there an indication that surface water of significant size had been affected in a measurable way by sump fluid chemicals. Even at this site, the rather high background salinity of the surface water reduced the significance of the change in water quality. Hrudey (1980), in reviewing the above study, felt that surface water pollution occurred at the time of reclamation or resulted from chemical spills during drilling operations. There appeared to be no long-term reductions in surface water quality.

In 1981, a study was conducted on southern Ellef Ringnes Island to assess the environmental effects of placing the waste drilling fluids directly upon the tundra. (See section 3.3). In the summer following drilling, French and Rossiter (1985) examined the local creek water quality and found that movement of drilling muds and fluids into the adjacent creek did not cause deleterious long-term changes in water quality. The leaching of toxic materials in the creek was slow and the soluble components, potassium, sodium and chloride were quickly diluted to background levels.

Lawrence and Wright (1975) conducted a study to establish the effect of waste drilling mud on a lake environment. Following the discharge of some 4500 cubic metres of waste sump fluid into a small lake (1.05 square kilometres) in northern Canada, they found an immediate increase in the concentration of certain ions in the lake. Iron increased from 0.35 to 0.70 mg/L, chloride from 4.1 to 7.25 mg/L and sulphate from 5.0 to 8.3 mg/L. Three weeks after termination of the discharge, the iron concentration was 4.0 mg/L, chloride 7.4 mg/L and sulphate 7.9 mg/L. No explanation was given for the increase in chloride concentration but presumably this small subsequent increase represents a sampling and analytical error. Conductivity also declined on termination of the discharge, but levels had not fallen to pre-pumping conditions after two months. Campbell (1975), in a field biological study of the above

lake, concluded that the simulated sump fluid spill had no measurable short term effects on the feeding habits or behaviour of fish populations in the receiving waters. No definite conclusions were reached about long term effects.

Only a small number of studies have investigated the environmental impact of drilling fluids on groundwater. If drilling wastes are completely frozen within sumps in permafrost regions in the Canadian North, little or no groundwater contamination is expected. However, in areas of warmer mean summer temperatures and discontinuous permafrost, groundwater contamination is possible. Hrudey et al. (1974), in an investigation of six abandoned sumps in the Mackenzie Delta, found that groundwaters within about 7 to 15 metres of the abandoned sumps were generally polluted with drill mud chemicals. These groundwaters were generally characterized by high concentrations of sodium, potassium, chloride, sulphate and organic carbon. The authors did not expect any significant movement of the pollutants because of the very low groundwater gradients at the sites.

Four reclaimed oil and gas well sites in western North Dakota were investigated by Murphy (1983) and Murphy and Kehew (1984). Chloride (the most mobile ion) at two of the sites had moved some 60 to 90 metres down-gradient of the sumps, while at the other two sumps, chloride had not even reached the water table. The movement of trace metals was attenuated by clay particles in sediments near the sumps and the semi-arid climate reduced the generation of leachate.

Indirect impacts on groundwater resulting from drilling fluid disposal include reduction in permeability because of clogging of pores by bentonite (Strosher et al. 1978) and reduction in permeability resulting from destruction of aggregation in soils beneath a spill by sodium (Miller and Pesaran 1980).

4.1.3 Regulatory Concerns

Present regulatory practice requires total containment and gives rise to relatively minor concerns. Other methods of handling waste drilling fluids are not specifically addressed by existing regulations. There are two primary areas of concern.

There is a lack of written procedures for dealing with typical field situations. Although there is a relatively long experience of sump fluid disposal and containment in northern regions within both government and industry, at present little of this exists in written guidelines or procedures. Staff turnover, especially during periods of economic downturn, results in the loss of valuable experience needed in dealing with the wide range of conditions encountered in the North. Written guidelines and procedures would positively affect both operators and regulators, speed up the Land Use Permit approval process and enhance current practice in the field.

There is a lack of policy and guidelines for emergency disposal of waste drilling fluids. The Territorial Lands Act and the Land Use Regulations adequately address the needs of total containment. Problems arise whenever there is a need for emergency decanting. Under the land use permitting process, there are neither policy nor guidelines to follow should such a requirement occur. Nor are operators required to prepare contingency plans during the permitting stage, or keep records of mud additives used during drilling, both of which could improve the decision making process.

When emergency decanting is necessary there is a very real concern that, should any of the waste fluid enter a body of water, one regulator's decision could be overruled by another regulator operating under the Fisheries or Northern Inland Waters Acts, exposing the operators to prosecution. The lack of a formal agreement and statement of policy among agencies, the absence of guidelines and the lack of appropriate contingency plans by operators results in a very conservative approach by regulators, often leading to delays and eventually forced, and sometimes ill-advised, decisions.

4.2 BEARING OF CONCERNS ON DRILLING OPERATIONS

4.2.1 Typical Operations

In this section, the significance of the various concerns is assessed by examining them in the context of the stages of a drilling operation.

4.2.1.1 Planning

Sump Location

Terrain conditions such as the presence of ice-rich soil, coarse-grained soils and rocks are often not taken adequately into account when locating a sump. Locations close to water bodies, low lying areas, drainage channels or swales should be avoided in order to reduce the possibility of surface water or groundwater intrusion into sumps.

Sump Size

Concerns related to sump size include:

i) Undersizing, which results in the need for enlarging an existing sump or blasting a new one. Enlarging an existing sump in permafrost usually results in some leakage. Blasting a second sump may negatively effect rig stability;

ii) Oversizing, which increases terrain disturbance and offers a larger perimeter for erosion. In permafrost, oversizing offers potential for greater thawing and slumping than if a smaller sump were used; and

iii) Cost is also a concern when it comes to sizing sumps. This is a very site-specific variable depending on season of drilling, length of drilling program and conditions expected. A 100 x 50 x 5 m sump costs about $800,000 in the Arctic Islands. A sump for a 1500 m well near Norman Wells costs about $60,000. Sizing includes about a 20 per cent contingency to account for increased drilling and the possibility of hitting a water-bearing formation.

Scheduling

There is a concern from both government and industry regarding the scheduling of drilling operations when sumps are constructed in ice-rich permafrost terrain. Thaw slumping and settlement may occur if a sump is left open over summer. Even in non-permafrost areas, sumps left over summer can experience wall erosion due to precipitation and inflow of surface waters. If single-season winter drilling is undertaken it is likely that terrain instability will occur.

However, if two seasons of winter drilling (i.e. the sump is left open during summer) or summer drilling are planned, terrain instability is likely to occur unless special measures such as inside wall insulation are incorporated in the design of the sump. Even this may not be enough to stop the development of thermokarst. Operations which extend into summer may increase risks affecting sump integrity, terrain stability, and accelerated erosion on the site. At present, summer operations are not typical as 80 to 90 per cent of wells in the North are drilled and completed in one winter.

4.2.1.2 Sump Construction

Cost

Construction of a sump is costly and can range from $14,000 in southern NWT areas which are easily accessible to $100,000 - $500,000 in coastal areas, the Mackenzie Delta and the High Arctic. Specialized equipment and expertise is required for sump construction particularly if blasting is involved (as in most permafrost areas). Time and expenses must also be invested by operators in site investigations, design and logistics planning.

Terrain Disturbance

Some operators view the excavation of a sump as a disturbance, which may be unwarranted in view of alternatives such as deposition of non-toxic fluids directly into natural depressions. However, a sump, even one the size of a football field, is generally accepted in current practice as a localized disturbance of the terrain.

If a sump is constructed in ice-rich terrain, there is a concern over sump integrity. If ice-rich spoil is excavated and left over a frost free period, it will thaw and flow, and if it refreezes, will be very difficult to move as fill. During construction, features such as ice or rock faults or ice wedges and lenses create a potential for slumping of the sump walls and floor, settlement around the sump and subsequent changes to overland flow patterns, leading to ponding and accelerated thawing of ice-rich permafrost. This may ultimately reduce the sump capacity and cause leakage of sump fluids.

Current practice accepts the terrain disturbances associated with the construction of a sump as a short term impact which can be mitigated by design and restoration measures implemented during abandonment.

Fluvial Erosion

Groundwater encountered during excavation can reduce the stability of the walls of the sump, enhance sloughing and reduce sump capacity. Contamination of groundwater with sump fluids may also occur. Surface water runoff can fill the sump and erode sump walls, resulting in the escape of sump fluids. Surface water or groundwater can also cause the sump to overflow allowing sump fluids to escape.

4.2.1.3 Sump Operations

Thermal Erosion

During operations, a number of environmental concerns arise. Relatively warm waste fluids (ranging from 5 to 90°C) are pumped into the sump and can melt ice-rich soils and ice lenses, resulting in sloughing of the sump walls and floor. Extended operations resulting in the sump being open over summer can lead to changes in the soil thermal regime and erosion in areas of ice-rich permafrost.

Fluid Volumes

If operations run longer than planned or the well is drilled deeper than anticipated, sump capacity may be exceeded and the need for constructing a second sump or finding an alternate method of fluid disposal may arise. Components such as washwater are a concern as they can

significantly add to fluid volumes, making up as much as 50 per cent of the total sump volume. Occasionally, effective sump capacity may be reduced if field operations require the sump to be open longer than expected allowing drifting snow or surface water to enter the sump.

Fluid Toxicity

The practice of total containment implies that no fluids will be released. Therefore fluid toxicity is not considered an issue, particularly if the sump has been located and constructed properly and is not to be left open during a period of thaw. However, if it is to be open over summer or if it is constructed in a non-permafrost area, it may be necessary to consider the possibility of fluid escape, in which case environmental toxicity of the fluids is a concern.

4.2.1.4 Decanting or Partial Containment

Regulatory Concerns

At present there is neither government policy nor guidelines to cover partial containment in Yukon or the Northwest Territories. The primary concern is the potential impact of the fluids on the environment. In Alberta, an environmentally acceptable policy and guidelines for sump fluid disposal have been in place for many years. Adoption of this policy by Yukon and the Northwest Territories has not taken place because of basic differences in drilling conditions in northern regions. Most drilling in the North takes place in the winter; operations are completed and all equipment off the land before breakup. With the exception of oil-based muds, most sump fluids freeze soon after reaching the sump, therefore making it very difficult to sample or treat fluids prior to decant. For partial containment or non-containment to be of any value under these circumstances, methods or procedures need to be developed which either permit rapid field assessment of fluid toxicity or allow for identification of sites which would have minimal environmental sensitivity to untreated fluid disposal. Although a number of fluid toxicity studies have been conducted in Alberta and elsewhere (section 4.1.2.2), little systematic research of this kind has been done in the North. Although the generalities of the Alberta work are transferable to northern biota, the specifics may still have to be tested prior to significant changes in policies for the Northwest Territories and Yukon.

Physical Concerns

The process of decanting has been relatively rarely used (less than 10 per cent of operators have requested decanting) and only then in special situations and where fluids have been shown to be non-toxic or have been treated to render them so. Decanting has support from operators in certain

situations, although it can be an added expense and does not eliminate sump infilling costs because sumps must be restored anyway. Decanting in winter is not possible if fluids are frozen in the sump, and even if thawed, they may freeze in decant pipes. When decanting the fluids in permafrost terrain, the potential exists for thermal erosion and the development of thermokarst. Ice build up around the rig is also a potential concern.

Chemical Concerns

Concerns about the chemical effects of sump fluids released to the environment must consider the sensitivity of the environment in which the fluid will be released and the toxicity of the sump fluid.

Environmental Risk

In the North, at present, no formalized method for environmental risk assessment exists. A formalized procedure or scheme of impact evaluation would be required to set chemical standards and guidelines. Existing information could be researched and compiled to provide the basis for this scheme.

Fluid Toxicity

Appropriate criteria are not in place to define chemical impacts and fluid toxicity in the North. Criteria are needed for evaluation of short term impacts under specific disposal conditions. They should include not only chemical standards but also a test of acute toxicity as a relative measure of expected environmental damage. Toxicity tests should be inexpensive, rapid, simple and performed on-site, if possible. Results must be reproducible and acceptable to both government and industry.

The procedure of sump fluid sampling to determine toxicity based on a representative sample can be difficult. For example, fluids in the sump are not uniform and during winter are mostly frozen. It is difficult to obtain a representative sample and get an accurate reading of toxicity. The sampling process itself is hazardous and sump fluid samplers currently in use are not adequate. Often there is not enough time to send samples to remote laboratories for analysis and obtain results before disposal of fluids becomes a necessity. Fish bioassays take four days, not including sample shipping time.

The relevance of the fish bioassay to on-land disposal of fluids is questioned by regulators and industry. Other bioassays, such as Microtox, are not frequently used but should be investigated with regard to their potential as toxicity screening tests.

Chemical concerns about partial containment are described in detail in section 4.1.2.2. In general, water/gel fluids are not harmful but potassium chloride fluids and oil-based muds are toxic to organisms and would result in vegetation damage if spread on land. Water/gel mud systems are generally not toxic to fish and vegetation (Strosher et al. 1978). As noted earlier, some components added to these systems can render a fluid toxic. Operators are concerned that a toxic component may somehow end up in the fluid and are unwilling to take a chance on less than total containment.

Regulators maintain that it is difficult to predict potential effects of fluids because little information is provided regarding their composition and toxicity. While much of this information is available, it is not in an easily accessible or understandable form.

Downhole conditions (such as saltwater formations) can also potentially turn a non-toxic mud into a toxic sump fluid. If fluids are to be released on land or in water, regulators must be able to quickly and accurately assess the toxicity of the fluids. Any treatments of fluids must be acceptable to government and industry.

One aspect of fluid composition which reduces much of the concern about toxicity is that the majority of fluids used in the North today are water/gels. The gel components are such products as XC polymer, which is commonly used in the food industry.

4.2.1.5 Abandonment and Restoration

Concerns about sump abandonment and restoration are primarily physical in nature and include the following:

i) There is usually only a short time available for completing the operations and abandoning the sump and well site before breakup. Under these conditions, a special effort is required to maintain a high quality of work on site;

ii) There may not be enough spoil remaining to sufficiently cover the sump. A partially covered sump in permafrost offers the potential for the collection of surface waters and subsequent melting of the frozen sump fluids and the surrounding permafrost, leading to release of the fluids. Even in areas where the surface drainage does not interfere with the sump site, insufficient cover increases the likelihood of the frozen fluids melting and the sump leaking;

iii) Undesirable items such as pipe, timber etc. should not be deposited in the sump. In permafrost, these may be heaved to the surface through frost action if they are not deposited below the active layer;

iv) Subsidence, ponding and leakage of fluids may occur upon abandonment if the sump has not been properly crowned. Ponding may take place when fill with a high ice content is used;

v) Oil-based muds are difficult to solidify in the sump. Similarly, potassium chloride drilling fluids will lower the freezing point of the mud. Unfrozen fluids in a sump increase the potential of melting ice-rich permafrost and leaking of fluids;

vi) The use of cats to fill in sumps in permafrost during summer may cause extensive terrain damage. Heavy machines may sink due to the low bearing capacity of soils used for capping the sump. The unfrozen fluids may be squeezed out of the edge of the sump. Backhoes or draglines may be more appropriate for backfilling to avoid these situations; and

vii) Increased physical disturbance and operating costs are associated with having to return to clean up or implement any remedial work at abandoned sumps and having to ensure revegetation success.

4.2.2 Atypical Operations

4.2.2.1 Drilling Without a Sump - Non-Containment

Physical Concerns

Natural depressions could be considered for disposal of non-toxic fluids. However, in reality the well sites are often located in terrain free from suitable depressions. In the absence of a suitable site for natural containment, measures are necessary to prevent the released fluids from ponding around the rig, forming icings or eroding the terrain. The high volume of fluids requiring disposal is an obvious concern. If 20 000 barrels (3000 cubic metres) of fluid (the average for a typical sump) were disposed of directly on land, this would be the equivalent of flooding 10 000 square metres (1 ha) to a depth of about 0.3 m. In summer much of this would be absorbed by soil, and in winter by snow. However, the fluids could flow for a considerable distance if their spread was not controlled. Non-containment of non-toxic fluids is a lesser concern in the Mackenzie Delta and some coastal areas, where spring flooding and storm surges occur, producing a natural flushing mechanism. Some environmental concern may exist during storm surges which take place during open water season, particularly in relation to birds during their nesting seasons.

Non-containment also raises the question of the impact of the waste solids. Disposal of the solids offers the opportunity of smothering vegetation, acting as a barrier to

drainage, and altering the thermal regime of the permafrost. The latter case occurs if the thickness of the solids is great enough to destroy the vegetation cover, yet not great enough to replace the insulation provided by the vegetation. Solids disposal may significantly change the albedo or the heat conductivity of the ground surface.

Chemical Concerns

Chemical concerns are similar to those for decanting. One divergence is in the area of fluid treatment. In situations where fluids are partially contained, there is an opportunity to test and treat the fluid. In non-containment situations, testing must be ongoing and treatment is necessary if a fluid is found to be toxic. A fluid holding tank might be used to contain the fluids just long enough for testing and treating prior to disposal.

Fluids with toxic salt levels such as potassium chloride-based muds or high hydrocarbon levels such as oil-based muds should not be considered for direct disposal to land or water, and should be contained or disposed of in an environmentally acceptable manner.

4.2.2.2 Other Methods of Disposal

Processes such as chemically enhanced centrifuging of fluids are costly and are a concern as the end product is highly toxic and must be kept dry. This raises the question of whether it is better to have a large amount of less toxic material or a small amount of highly toxic material. Processes such as enhanced freezing (dilution with fresh water) are viewed favourably for freezing saturated salt solutions. Downhole injection is costly because completion crews must remain on site longer. Downhole injection requires special precautions to ensure it is a safe and acceptable disposal option as the fluid may contaminate groundwater.

Fluids such as oil-based muds may be incinerated. This requires the use of specialized equipment on site. With efficient incinerators, it is a safe and effective method of disposal. Currently, less than 1 per cent of wells drilled in the North use oil-based muds.

The process of waste concentration by evaporation, used in southern environments, is not feasible in the Arctic because evaporation is very low. However, this technique may have some potential in southern areas of Yukon and the NWT where evaporation rates are higher. Evaporation does not reduce the toxicity of the material, only the volume: evaporation concentrates toxicants.

PART 5

APPROACHES TO THE DISPOSAL OF DRILLING FLUIDS: DISCUSSION AND RECOMMENDATIONS

5.1 INTRODUCTION

The earlier parts of this report have described the nature of drilling fluids, current practices for disposing of them, and concerns raised by their disposal. Three main approaches emerge from this review: total containment of fluids in a sump that is infilled on completion of drilling; partial containment of fluids using a sump but decanting some of the fluid for disposal on land or in water; and non-containment involving direct disposal of fluids on land.

There are a number of infrequently used variations on these approaches. For example, the use in Alaska of sumps that are not infilled but are intended to achieve total containment, the use of downhole disposal and the incineration of oil-based muds. Partial containment methods may differ depending on whether decanting is planned or required on an emergency basis.

In order to make recommendations about the use of the three approaches, it is necessary to consider two matters in addition to the material already reviewed. These are potential changes in drilling practices and the very large geographical variation in the North that may affect the choice of approach. After dealing with these, this chapter proceeds to offer suggestions for the practice of each of the main approaches in turn.

5.1.1 Future Drilling Practices

Drilling technologies and procedures are constantly changing. Such changes may influence the degree to which the disposal of drilling fluids poses a potential for environmental damage in the NWT and Yukon.

In all probability, future Arctic wells will be drilled to increasingly greater depths, resulting in an increase in the quantities of effluents generated. If sumps are used, these larger effluent volumes will necessitate the construction of larger sumps. A similar situation will occur with an increase in "cluster drilling" practices. This technique enables several wells to be drilled from one rig set-up.

In the future, non-toxic or less toxic additives should be identified and incorporated into the mud recipe in place of more toxic additives with the same functions. These substitutions may include less toxic non-chromium dispersants for lignosulphonate, less toxic detergents for rigwash, barite containing fewer heavy metal impurities and less toxic corrosion inhibitors and bactericides.

Oil-based muds may be used more frequently for well development. Because of their toxic nature, care must be taken to separate these hydrocarbons from the other waste effluent. The guidelines and regulations suggested below do not consider oil-based muds. Greene and Engelhardt (1984) stated that "there are no engineering constraints related specifically to the use of oil-based drilling muds which need to be taken into account in the development of environmental guidelines". This has been disputed by Hrudey (pers. comm.) on the basis that a suitable process for the removal of hydrocarbons has not yet been reported in the literature. Such a process would require removal of both immiscible hydrocarbons and water soluble hydrocarbons.

5.1.2 Geographical and Terrain Constraints

Areas covered by the Territorial Lands Act and the Land Use Regulations encompass, by definition, the entire NWT and Yukon. Environmental concerns can only be identified within the context of local conditions. For example, what constitutes a significant environmental impact and what is considered a "significant" or "sensitive" environment will vary between geographical areas. Important geographical considerations include the presence or absence of permafrost, the climate of the region, native vegetation, soil characteristics and topography.

Permafrost is perennially frozen soil. It may occur as continuous permafrost where permafrost is present everywhere under the ground surface, or as discontinuous permafrost where there are areas of both permafrost and unfrozen material. The term "ice-rich" permafrost is used to describe ground that is made up of fine-grained sediments possessing ground ice in excess of interstitial or pore space.

Permafrost considerations are important since the rationale for containment in below-ground sumps rests on the assumption that permafrost is relatively impermeable to waste fluid migration and that this fluid will eventually freeze in situ (French and Smith 1980). A distinction must be made between locations in continuous permafrost, those in discontinuous permafrost and those in areas subject only to seasonal frost. In areas of discontinuous permafrost it is difficult to achieve full containment. Such areas are prone to terrain instability and any melting of ground ice may trigger accelerated erosion which can jeopardize sump integrity.

Important climatic factors include the depth of seasonal freeze and thaw, snowfall amounts, the duration and speed of the thaw period which influences snowmelt runoff amounts, and lastly, the length of time between onset of spring thawing and winter freeze-up. This determines when heavy vehicles and sump construction equipment can be moved over frozen substrate. Canada's North has an annual average of only 40 to 60 frost

free days north of the treeline. Above the treeline, permafrost varies in thickness from about 100 m to 1000 m and below the treeline, some areas are completely free of permafrost.

Climate, particularly mean annual summer temperature, influences plant growth and, to a large degree, determines the extent of the boreal forest, shrub tundra, tundra and desert ecosystems in Arctic Canada. The rate of revegetation and/or reclamation of disturbed sites is largely influenced by summer air and ground temperatures.

Surface and subsurface soil characteristics influence the porosity and permeability at a particular site. Secondly, they affect the availability of nutrients for plant growth. They also influence groundwater and surface water infiltration and migration. Acidic, alkaline and neutral soils support different plant assemblages. Therefore the biological impact of a given waste effluent may not be the same in different locations even within the same climatic zone.

Hilly sloping terrain and/or the presence of surface drainage, water courses and lakes may impose limitations in locating sumps and disposing of waste effluent. The possibility of flooding, and the eventual erosion of sumps by stream action, coastal retreat, or slumping must all be considered.

Regional variability does not automatically favour a specific policy of either containment, partial containment or non-containment for any geographic area. Instead, regional geographic differences merely highlight the need for flexibility in waste drilling fluid disposal procedures.

The High Arctic Islands, because of their remoteness and the polar desert and semi-desert environments of much of the landscape, provide the best opportunities to undertake partial containment or non-containment procedures. Total containment may be most appropriate in certain locations underlain by coherent bedrock, such as Stokes Range, Bathurst Island. In other areas which are underlain by ice-rich and weakly-lithified sediments such as Sabine Peninsula, Melville Island and southern Ellef Ringnes Island, partial containment or non-containment may involve the least environmental impact. On the other hand, in certain arctic "oases", ecological, aesthetic and social reasons may necessitate a policy of total containment and burial. This might include locations such as Polar Bear Pass, Bathurst Island, Thonisen River Valley and Banks Island.

The Mackenzie Delta, including both the Modern and Pleistocene Deltas, is a unique ecological region. Here, site-specific factors may be the major determinants of waste drilling effluent disposal policy. At Parsons Lake, for example, the presence of hilly topography, ice-rich terrain and numerous lakes suggest that serious consideration be

given to partial containment and decanting. The Mackenzie Delta floodplain is also well suited to partial containment or non-containment on account of the ice-rich nature of the materials and the seasonal flooding of the Mackenzie River. In other localities in the Mackenzie Delta region, however, the human utilization of the area by hunters and inhabitants from Inuvik, Aklavik and other settlements may necessitate total containment, either in below-ground or above-ground sumps, depending upon the availability of sump wall aggregate.

The lowlands of the Mackenzie Valley are underlain by ice-rich, silty sediments and, if the forest cover is unnecessarily disturbed, high ambient air temperatures in summer will promote thermokarst. In addition, the warmer permafrost conditions and the presence of discontinuous permafrost and groundwater movement in the southern areas argue against a policy of above-ground containment or partial containment with decanting.

The interior plains and plateau of Yukon, including Eagle Plain and Peel Plateau, represent drier environments than the Mackenzie Valley Lowlands. They are also underlain by less ice-rich and more strongly lithified sediments. As a consequence, below-ground containment or partial containment may be appropriate. The use of borrow pits as sump locations (e.g. Aquitaine Alder C-33 well site) is a good approach for the Eagle Plain area. On Peel Plateau, a policy of containment following appropriate site selection appears suitable.

In the non-permafrost regions of the NWT and Yukon (e.g. Pointed Mountain area) environmental regulations and guidelines currently in place should be maintained. These require partial or total containment of waste drilling fluids.

5.2 TOTAL CONTAINMENT

The current practice of total containment of waste drilling fluids is generally well accepted by industry. Regulators consider it basically sound. Although it is subject to a number of concerns, most of them are relatively minor. By following current accepted standards of construction and maintenance, this method of handling waste fluids leads to a predictable level of impact on the environment. Government, industry and the public accept the impacts on the physical environment and assume that chemical impacts are non-existent because fluids are not released to the environment. Even if a gradual global warming trend were to take place, a likely consequence would be that the gradual degradation of permafrost and eventual sump breakdown would result in a slow release of fluids into the environment.

Total containment of all waste drilling effluents should be mandatory when:

i) Waste effluent is shown to be highly toxic to aquatic life and where aquatic life is likely to be significantly affected by its release;

ii) A large number of development wells at one location generate an exceptionally large volume of waste effluent, of a quality which could not be discharged directly without irreversible change to the environment. Current acceptable criteria for land disposal in Alberta are:

Chloride	=	1000 mg/L
Sulphate	=	2000 mg/L
TDS	=	4000 mg/L
pH	=	5.4 to 8.5

iii) Any contamination of the local groundwater or surface water must be avoided for ecological or health reasons. In such cases sumps should be located "a minimum of 100 metres laterally from the high water mark of the nearest waterbody and intermittent water courses" (Environmental Protection Services 1981); and

iv) The well site is located in an area of ecological or economic importance that must be protected from the impact of any release of drilling fluids.

Government and industry agree that while total containment is an environmentally acceptable method of handling waste drilling fluids, improvements to current practices can be made. The remainder of section 5.2 outlines areas where improvements should be considered.

5.2.1 Regulatory

Land Use Approval Process

Although this process appears to be a one window approach (i.e. application is made through INAC), the requirement to have all permit applications reviewed by a Land Use Advisory Committee that includes representatives of various agencies can be time consuming. It appears that the lack of a clear and integrated definition of standards necessitates each group reviewing a permit application to assess compliance with its concerns. The shortening of this process will require that the areas of concern and conditions acceptable to the various agencies be defined. An integrated standards manual could be prepared, and the requirement for appropriate information needed to assess compliance stipulated on the land use permit application form. Once standards and limits are understood and agreed upon, one agency could process applications utilizing other agencies for backup or clarification as

needed. This would lead to better planning by operators and enhanced practice in the field. The approval process could be shortened because more detailed planning information would be available from operators and improved performance would result from better direction and guidelines.

Procedures Manual for Dealing with Typical Field Situations

The recently released INAC document, Environmental Operating Guidelines: Hydrocarbon Well-Sites in Northern Canada, (Spencer 1987), provides a good overview of appropriate operating procedures for well site development and abandonment. However, more detailed information is needed about sump development, operation and abandonment. Industry and government rely heavily on the experience of their field personnel in dealing with a wide range of field problems. Unfortunately, employee turnover can result in the loss of years of valuable experience important in maintaining acceptable standards. Guidelines providing detailed procedures for dealing with fluid containment and disposal would ensure consistency in design and provide a sound basis for making innovative improvements. Key areas should be identified and good operating practice and procedures outlined. Topics covered should include sump construction techniques for various geographic and permafrost conditions, methods of sizing, and possible methods of enlarging sumps during summer.

Development of Guidelines for Emergency Decanting of Drilling Fluids

A statement should be prepared that defines emergency decanting and clearly outlines the roles and responsibilities of the Land Use Inspector and Land Use Engineer when an emergency decant is necessary. The statement should also define the interrelationship of the Land Use Inspector with those agencies enforcing the Northern Inland Waters and Fisheries Acts. A memorandum of agreement may have to be drawn up between these agencies to better define roles, responsibilities and procedures in the event of emergency decanting. One area of particular concern would be to define what constitutes entry of a decanted fluid into a water body, triggering the requirement to apply for a water license under the Northern Inland Waters Act.

5.2.2 Planning

During planning for development of a rig site, operators should assess environmental and geotechnical conditions and determine the best location for the sump. Although subsurface geological conditions determine where the rig site is located, the operator must familiarize himself with site specific conditions and optimize the location of facilities at the site. Sources of information that can be used in planning include air photographs, seismic data, topographic and geologic maps and a site investigation.

Sump Location

The site investigation is best carried out when the ground is free of snow. Information should be collected on soil conditions (especially the presence of ice-rich permafrost), drainage characteristics, presence of groundwater, and topographic conditions. Potential locations for a second sump and preferred areas for the release of decant should also be considered at this time. Contingency plans should also be developed for any site-specific concerns.

With respect to adverse terrain, test holes should be drilled to determine subsurface conditions. If a 1 m or greater ice lens is present, a new sump location should be investigated. High ground is good for sump location because it is the best drained. Medium to fine textured soil is preferable in discontinuous permafrost.

Locating the sump in relation to the rig will depend on site-specific terrain conditions. In continuous permafrost, locations downslope of the rig are preferable. If the sump is upslope of the rig and failure occurs, the fluid may cause thawing of the permafrost and terrain instability around the rig. Locating the sump downslope eases disposal of washwater. Locating upslope may be desirable under certain topograhic and terrain conditions. If the sump has to be located on fill, the fill should be compacted to decrease permeability.

Sump Size

Sumps are designed to account for volumes of fluid produced from regular drilling plus those volumes which result from unexpected extended drilling or downhole conditions. Experience suggests that in addition to this, a further oversize contingency is often required to ensure that the sump does not overfill. The added cost and terrain damage incurred as a result of oversizing appears to be warranted in light of the alternative of overfilling and having to construct a second sump.

Consideration should be given to constructing deeper sumps than is currently the practice. This will decrease the areal extent of the terrain disturbance. The limiting factor in this consideration is the depth to which a D7 cat can excavate (about 5.5 m). This is still approximately one metre deeper than normal sump depth. A sump 100 x 40 x 5 m has the same volume as one 100 x 50 x 4 m, but has a sump perimeter 20 m shorter.

Methods of easily and safely enlarging a sump when overfilling is imminent are not readily available. Such methods should be investigated and made available to government and industry.

5.2.3 Sump Construction

Terrain Disturbance and Scheduling

The main concern regarding terrain disturbance caused by sump construction is related to maintaining integrity in ice-rich, thaw-unstable permafrost. Sump construction, operation and restoration in a frozen period generally causes no problems. Therefore, this winter-only scenario usually ensures stable conditions around the sump. Summer operations are occasionally unavoidable. Procedures currently in practice to maintain sump integrity over summer are ineffective in preventing terrain instabilities at the sump site and therefore must be reviewed.

Fluvial Erosion

As long as adequate planning is undertaken prior to drilling, and the terrain is adequately accounted for in locating the sump, no overland water is likely to be intercepted by the sump. Erosion problems induced by surface water are therefore unlikely.

Groundwater encountered during construction can have an erosive effect on sump walls. Contamination of groundwater with sump fluids is also undesirable and should be avoided. This may require installation of an impermeable liner in the sump. However, use of a liner may not always be feasible and other methods to prevent contamination of groundwater should be investigated and made available to operators. The best solution, if possible, is to locate the sump where groundwater is not present.

5.2.4 Sump Operations

Thermal Erosion

In thaw-unstable permafrost, warm waste fluids can lead to terrain instability and thaw slumping. Thermal erosion is usually relatively easily reduced by cooling warm sump fluids prior to discharge into the sump. Directing discharge away from sump walls can assist in reducing thermal erosion in sumps.

Fluid Volumes

Occasionally fluid volumes are higher than expected and a sump may overfill. One way of reducing fluid volumes is to reduce washwater, which can make up as much as 50 per cent of total volume. High-pressure, low-volume sprays and the use of steam have been shown to be effective wash methods and both reduce the volume of washwater required.

Sump management related to water use in muds is quite strictly controlled by operators, but some improvement is possible. Metering of both pre-drill water volumes in mud and post-drill sump fluid volumes would assist the operator by providing information about the rate at which the sump is filling and whether or not downhole water is being picked up (from groundwater or saltwater caverns for example).

Processes such as reverse osmosis, chemically enhanced centrifuging, filtration, self-contained recirculation, sonic dehydration, evaporation and downhole injection should be more closely examined for their potential in reducing fluid volumes. Volume reduction is viewed as an industry initiative; the onus is therefore on industry to utilize these processes as may be dictated by cost/benefit analyses.

5.2.5 Abandonment and Restoration

Unwanted materials such as metal, wood and concrete are often deposited in sumps. Better controls must be introduced to ensure that such materials are removed from the site or, if possible, incinerated.

Volumes of soil material stockpiled during sump construction should be sufficient to infill the sump and cap the frozen fluids (roughly 1 m of cap is required for every 1 m of frozen fluid). Where insufficient material is available at the sump site, excavation of a borrow pit must be planned.

Fluids in the sump should be completely frozen prior to capping to minimize slumping and settlement. Occasionally sumps are infilled before fluids completely freeze because salt-based muds resist freezing. If necessary, fluids with low freezing points should be diluted with water to ensure that they will freeze prior to capping.

The operator must be prepared to infill the sump properly and return to the site if subsidence or settlement offers the potential for significant environmental damage. Regulations must reflect this obligation of the operator and regulators must make rational assessments of when remedial work is required. Sumps should be infilled when the ground is frozen. Infill material should not be allowed to melt (as in a two season operation) because, if it is ice-rich, so much may be lost that complete infilling is impossible. Care should be taken when infilling to exclude snow from the sump and compaction of the frozen infill should be maximized. Movement of heavy earth moving equipment at the sump site, both during construction and at the time of site rehabilitation, should be monitored and restricted to the immediate vicinity in order to minimize the area of terrain disturbed.

5.2.6 Use of Open Sumps

To minimize terrain disturbance, the possibility of using "open" above-ground sumps such as those in northern Alaska should be considered. These sumps are not infilled and become permanent features of the landscape. They could be used in the following situations:

i) If the permafrost is ice-rich and sump excavation would destroy insulating surface vegetation and induce thermokarst activity. Thermokarst is initiated when the ice-rich permafrost melts, releasing latent heat, and inducing further thawing;

ii) If a natural depression or enclosed water body is present and, for aesthetic or other practical reasons (steep slopes) it is felt desirable not to create unnecessary terrain disturbance with heavy vehicles (i.e. tracked vehicles such as bulldozers);

iii) If the sump walls could be constructed from local materials, which could be hauled in winter and arranged in such a way as to give a "rounded" or "natural" appearance (as in Alaska);

iv) If a synthetic liner is placed within the sump to prevent leakage of waste fluids through the walls; and

v) If construction of a below-ground sump might: (a) prove to be physically very difficult (e.g. if the site is underlain by ice-rich shales, or is highly susceptible to thaw erosion and slope instability); (b) damage adjacent structures through use of explosives; or (c) contaminate groundwater.

5.3 PARTIAL CONTAINMENT

In certain locations, the partial containment of waste drilling effluent may be the disposal technique that best reduces environmental damage. Such a procedure requires a small sump large enough to contain, on a temporary basis, the entire volume of drilling effluent which might be in circulation at any time during the drilling operation. That is, the sump must have the capacity to hold all drilling fluids in case of a downhole emergency. Some of the fluids are decanted from the sump from time to time, avoiding overflow. Most of the recommendations under "Total Containment" that apply to sump location, construction and abandonment also apply to partial containment. Further discussion is required of where and when partial containment is advisable and how and when decanting should occur.

Partial containment may be appropriate wherever total containment is not necessary or where conditions are not favourable for non-containment. A large water body or a stream should be available to dilute the supernatant waters, or conditions similar to those required for direct on-land disposal should exist. Unusually large volumes or acute toxicities of drilling fluids, highly valued environmental or social components at the site, and geotechnical and groundwater features can provide grounds for rejecting partial containment for a particular well.

The remainder of section 5.3 examines the practice of partial containment in detail and recommends improvements.

5.3.1 Regulatory Aspects

Some of the regulatory recommendations in section 5.2.1 apply to partial containment as well.

Guidelines for decanting (i.e. fluid release) should be developed. While procedures for summer disposal could follow Alberta's ERCB guidelines, the constraints of operations under extremely cold conditions need to be taken into account with provisions for limited or rapid fluid testing techniques allowing for immediate fluid release. This would have to be accomodated in the specific plans for a well site and in the relevant regulatory permits. Planned decanting would require:

i) Good information on terrain conditions so that fluid movements could be predicted and assessed in advance;

ii) The use of only "government approved" additives for those stages of the drilling operation where fluids would be released; and

iii) A rapid on-site method for determining acute toxicity should fluids pick up contamination (hydrocarbon or salts) from the formation. This could involve conductivity testing for land disposal and/or microtox for freshwater disposal.

Whenever possible, decanting should only involve supernatant sump waters, and all muds should be retained in the sump. Decanting of supernatant waters from the surface hole should be automatic, while decanting from the intermediate hole should be discretionary, depending upon the mud recipe used, the volume of waste effluent involved and the degree to which snow has infilled the sump. One of the main objectives of decanting is to reserve volume in the sump adequate for total containment of waste effluent associated with the main hole and/or any extensions to drilling which might occur at a later stage. It is during the latter stages of drilling that the waste effluent contains the most additives.

5.3.2 Physical Aspects

Methods of effectively decanting fluids in winter must be developed. If the drilling operation is a one season winter operation, decanting must occur before the liquids freeze in the sump. Decanted liquid should be directed towards the lines of natural drainage away from the site. Fluids will have to be sampled as they enter the sump before they can freeze. Pipes carrying fluids must be heated to prevent freezing.

In a two season operation, decanting of sump supernatant waters should take place before or during snowmelt runoff, but only after the sump fluids have thawed completely and allowed heavy solids to settle.

Consideration should be given to decanting or disposing of waste drilling fluids into suitable water bodies. This may involve release into a stable water body (i.e. a lake that does not turn over) or a sterile water body (such as an ephemeral stream channel) in the polar desert. In the Mid and Low Arctic, release may be possible into large rivers at high discharge, where the fluids will be rapidly diluted. Release onto active floodplains, where dilution would also occur, should also be considered. In all geographic areas, release onto ice and subsequent dilution during breakup also warrants consideration.

5.3.3 Chemical Aspects

Chemical concerns outlined in Part 4 could be considerably alleviated if fluid makeup were planned to include non-toxic components wherever possible. Rather than attempting to reduce toxicity of a sump fluid (i.e. after drilling), it would be less costly to ensure that only non-toxic components entered into a drilling mud. A list of drilling mud products approved for Yukon and the NWT would be helpful to both operators and regulators to ensure that the least toxic components were used. This list would include maximum allowable quantities (per barrel) of toxic components. Lists similar to this have been developed by the US Environmental Protection Agency for Alaskan drilling and INAC - NAP for Canadian Arctic offshore drilling.

To ensure that the toxicity of sump fluids is assessed there is a need for a screening procedure, even if the components added suggest that the fluid is non-toxic. Chemical criteria which would be important to evaluate would include:

- pH;
- Salinity (electrical conductivity);
- Solids content; and
- Oil and grease.

In addition, an acute toxicity test would be helpful to ascertain the relative toxicity of fluid to the environment. Pass/fail standards must be defined for all tests. The ERCB guidelines may be a logical starting point when defining standards. The most complex aspect of the testing would be that of the acute toxicity test (bioassay).

If a fluid fails the regulatory standard, it is up to the operators to treat the fluid to enable it to pass. Fluids that pass the tests, whether treated or not, could be decanted at any stage of the drilling operation. Many procedures are available to operators to assist in reducing fluid toxicity. Some of these include:

- Flocculation;
- Dilution;
- Filtration and ultrafiltration;
- Improved solids control;
- Chemically enhanced centrifuging;
- Anaerobic biological treatment;
- Incineration; and
- Reverse osmosis.

Each of these may have merit as toxicant reducing procedures. It is up to industry to use them where and when needed, and as cost/benefit analysis indicates, to meet standards for disposal. Government and industry agree that industry should continue to improve these processes as the need arises.

5.3.4 Bioassays

As described earlier, an acute toxicity test is required to screen toxic fluids so that they are not released into the environment. The physical process of sump fluid sampling in northern sumps must be improved to obtain samples that are representative. Experience confirms that sump contents are not always homogenous and may be frozen. Sump fluid samplers must be redesigned to make them easier to use.

Currently in Alberta most sump fluids must be screened by a fish bioassay before they are released off-lease. The test is described in section 4.1.2.2. Advantages of the fish bioassay are as follows:

- Vast historical data;
- Recognized and accepted by government and industry; and
- Correlated to freshwater aquatic systems.

Disadvantages for use in the North are:

- Slow (minimum 96 hours);
- Not correlated to saltwater habitats or terrestrial systems;
- Virtually impossible to undertake on site;
- Expensive and time consuming; and
- May not detect sublethal effects.

As noted in section 4.1.2.2, the test is normally carried out with rainbow trout, a southern species. Use of a northern species, such as the threespine stickleback, should be studied (Soniassy 1983).

The slow turn-around of the fish bioassay may be avoided by using the microtox bacterial bioassay which is not yet officially accepted for use as a screening method but is showing strong correlation with the fish bioassay. The microtox bioassay measures the sensitivity of a marine luminescent bacterium to a wide variety of toxicants. The amount of light emitted by the bacterium when it comes into contact with the test fluid is measured by the microtox apparatus and correlated to known standards over time. Advantages of the microtox bioassay are:

- Results in less than 45 minutes;
- It is portable and could be used on-site in the field;
- Correlates with the fish bioassay;
- Costs are relatively low ($20,000 - $30,000) for initial equipment purchase and moderately low for each test run.

Disadvantages are:

- Poor correlation with terrain damage;
- Bacteria must be kept frozen;
- Operator must be well trained;
- Regular, frequent quality control samples may be required; and
- At this time, the microtox test has only a short history of use.

A pass/fail standard has been suggested for Alberta (LC 50 at 90 per cent concentration or greater to pass), but the applicability of this standard to northern Canada must be examined. Quality assurance methodology for the microtox system must also be developed to minimize operator variation, particularly if tests are to be performed on site.

Other bioassays using seed, nematodes and algae also hold some potential as toxicity screening processes. In each case, further work is required regarding reproducibility and correlation with expected environmental damage.

5.4 NON-CONTAINMENT

In contrast to a planned decant in which less toxic portions of the drilling fluids are decanted and more toxic portions contained in a sump, non-containment involves the total disposal of fluids and cuttings to the surrounding environment. In certain carefully defined environments this practice may be consistent with sound environmental management. In these instances, use of an extremely small sump (to hold effluent in case of an emergency) or a sumpless operation might be permitted.

Locations where non-containment may be acceptable may also be areas where either partial containment or total containment procedures would work equally effectively. Non-containment should be considered only as an option of the last resort, to be recommended only after evaluation of partial and total containment for the location in question.

Guidelines are needed to assist integration of assessments of the sensitivities of receiving environments and the toxicities of disposed fluids and cuttings: the less sensitive the environment, the less concern about controlling fluid toxicity and vice versa. Guidelines are also needed to minimize terrain disturbances as a result of cuttings disposal. As in the case of emergency decanting, a policy reconciliation concerning water pollution is needed between agencies enforcing the Territorial Lands Act and those dealing with the Northern Inland Waters Act, Fisheries Act and Arctic Waters Pollution Prevention Act.

Locations where non-containment might be an acceptable procedure include:

i) Floodplain locations in the Mackenzie Delta where annual floods will disperse waste effluent quickly and efficiently;

ii) Ice-rich areas, where construction of any sort will pose serious hazards to rigs, and where the potential for thermokarst is to be avoided at all costs especially in the case of two season operations;

iii) Barren, polar desert and semi-desert environments of the High Arctic Islands, where either plant and animal productivity is low, public water use is minimal, or sediments are ice-rich; and

iv) Topographic conditions where containment or partial containment procedures would not be effective. Examples would include well sites located in stream beds, or on extremely small land surfaces such as islands or ridgetops.

If non-containment is permitted there are two possible strategies:

i) To dispose of waste effluent as quickly as possible over as wide an area as possible, in order to lower the concentrations of harmful contaminants, and to reduce "smothering" of vegetation with muds; or

ii) To contain waste effluent in as small an area as possible, thereby increasing physical damage to plants by smothering, but restricting the areal extent of such damage.

Because of the difficulties associated with spreading frozen muds, greater terrain disturbance will result if the former is attempted. Mud disposal in areas of permafrost poses a special concern - the mud should either be thin enough to avoid destroying the insulating vegetation cover or thick enough to create a new layer of insulation. As one moves south, the preservation of permafrost requires a greater thickness of mud cover and decreases the practicality of this approach.

To prevent erosion, local terrain features such as slopes, lakes and water courses must be evaluated and flow must be directed away from erodible or sensitive areas. To avoid triggering accelerated erosion, energy dissipators should be in place on decant outlets or consideration should be given to spraying the fluids, rather than discharging them directly on land.

In the High Arctic, depressions (first order stream channels) should be considered for disposal in non-containment situations. In unfrozen soils, deposition in depressions should be avoided; the waste material should be spread out to allow for faster natural processes. Unfrozen soils also offer the opportunity for soil mixing, followed by reclamation. Mixing should take place at the rig site or off-site in an already disturbed area. In non-permafrost areas, disposal in bogs could be considered.

PART 6

RECOMMENDATIONS FOR FOLLOW-UP ACTION

6.1 REGULATORY ASPECTS

REG* 1) Develop guidelines that integrate the requirements of all responsible government agencies and special interest groups regarding the planning, construction, operation and abandonment of sumps. Provide operators with better information on requirements from regulatory agencies. Reduce the need for consultation among agencies. Facilitate more efficient processing of permit applications.

REG 2) Develop guidelines for emergency and planned decanting. Specify the conditions under which decanting would be considered and the objectives to be achieved. Suggest a definition of what constitutes entry of a decanted fluid into a water body and under what circumstances a discharge of waste drilling fluid requires a Water License.

REG 3) Define the role and responsibility of the regulatory agencies in relation to the guidelines and permits for decanting. State explicitly any discretionary powers. Clarify relationships among agencies concerned.

REG 4) Develop a measure of environmental risk or method of impact evaluation to assess the sensitivity of the environment into which a waste drilling fluid can be released. Consider a variety of conditions such as geography and permafrost in the regions with potential for hydrocarbons.

6.2 PLANNING

REG 1) Outline the planning procedures required of the operator regarding sump location. Define the objectives and components of site-specific investigations. Suggest a source list of possible data available to facilitate project planning and investigations.

REG 2) Specify factors to be addressed in contingency plans required from the operator in the event of sump overfill or fluid escape. Develop the details of what is required in the plans and in the operator's response capability on the site.

* Denotes whether recommendation is intended for Regulators (REG) or Operators (OPER).

6.3 PHYSICAL ASPECTS

6.3.1 Sump Size

REG OPER 1) Compile, and make known to all operators, the methods of minimizing sump size.

REG OPER 2) Develop methods of easily and safely enlarging a sump during operations.

6.3.2 Sump Construction

REG OPER 1) Upgrade design and operational requirements to maintain sump integrity during operations over summer.

REG OPER 2) Develop guidelines to be followed in the event of encountering groundwater during sump construction. Develop methods of preventing the contamination of groundwater by sump fluid.

6.3.3 Sump Operation

OPER 1) Compile and make known to operators the methods of reducing volumes of washwater.

REG OPER 2) Direct continued effort and incentives toward the development of procedures which reduce sump fluid volumes.

6.3.4 Abandonment

REG 1) Implement a field survey of typical selected abandoned sumps in permafrost and non-permafrost areas to assess the adequacy of sump fluid containment achieved under the current practice of total containment.

REG OPER 2) Ensure adequate disposal of unwanted debris or substances such as metals, concrete, wood and chemicals so that they do not end up in the sump.

REG OPER 3) Review groundwater protection measures related to sump fluid disposal. Suggest design measures to prevent groundwater contamination. Specify the information requested from the operator to obtain an approval for downhole disposal with respect to protection of groundwater.

6.4 CHEMICAL ASPECTS

REG OPER 1) Compile a list of mud additives used in operations on land in Yukon and the NWT. Define data needs on the potential impacts of additives on the northern environment. Review the information available and identify data gaps. Recommend procedures for testing and approval of new products.

REG 2) Review and improve sump fluid sampling techniques to ensure representative samples are taken for testing.

REG OPER 3) Redesign equipment for sampling of sumps in frozen or unfrozen form to ensure it is safe and suitable for collection of representative samples.

REG 4) Develop guidelines which include suggested chemical criteria (pH, solids, salts etc.) on a pass/fail basis for a waste drilling fluid which is to be disposed of on land or in water. Review chemical criteria presently used in Alberta by the ERCB and those used in other areas, and suggest pass/fail parameters for northern regions.

REG 5) Adopt a bioassay to test the acute toxicity of fluids destined for disposal on land or in water. Review a variety of bioassay techniques with the goal of finding one that is rapid and inexpensive. Include the Microtox Bacterial Assay in this review. Develop quality assurance methodology and pass/fail parameters for northern regions for any bioassay selected.

REG OPER 6) Direct continued effort and incentives towards development of methods of treating fluids to reduce their toxicity. Test present methods used in southern Canada under conditions in the Canadian North.

PART 7

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